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THE CONTROLLED RETRACTING INJECTION POINT (CRIP) SYSTEM: A MODIFIED STREAM METHOD FOR *IN SITU* COAL GASIFICATION

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THE CONTROLLED RETRACTING INJECTION POINT (CRIP) SYSTEM: A MODIFIED STREAM METHOD FOR IN SITU COAL GASIFICATION

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ABSTRACT

The underground coal gasification process, in practice, is subject to various problems that make it difficult to maintain and control an efficient long-term operation. One of the major problems is the need to move the injection point (where the combustion-supporting air or oxygen from the surface is fed into the coal seam) to new areas of unburned coal as the burn progresses. To achieve better control of the gasification process, we recommend the controlled retracting injection point or CRIP system. With this technique, the operator can choose the optimum time and distance to move the injection point, and consequently the burn zone, to get the best possible performance from the gasification process.

INTRODUCTION

Coal is gasified underground by drilling boreholes into the seam, igniting the coal, and injecting air or oxygen and steam to support the combustion in the underground reaction zone. The coal is partially oxidized, producing gas of low or medium heating value. The hot product gas flows through a channel in the coal seam to the exit boreholes and thus to the surface where it is processed for use.

The methods currently in use for *in situ* coal gasification suffer from a number of operational handicaps. With the standard arrangement--injection well, linking channel, production well--the burn zone geometry is constantly changing as the cavity grows around the injection well toward the production well and up to the roof rock. Roof collapse fills the cavity with inert material, providing an opportunity for oxygen to bypass the reaction zone and oxidize the product gas, lowering its quality. Heat loss increases as more and more roof material is exposed, with consequent lowering of the heating value of the product gas as the temperature of the reaction zone drops. Vertical injection wells are subject to an extremely harsh environment of high temperatures, corrosive gases, and massive mechanical forces from rock motion.

There is strong evidence from the Hoe Creek experiment[1] that maintaining the injection point at a low position in the coal seam is essential for obtaining good gas quality and high resource recovery. But maintaining a low injection point is very difficult with a vertical injection well. The desire to establish a more constant burn geometry and to ensure a seam-bottom injection point led to the concept of the controlled retracting injection point or CRIP system described here.

HOW THE CRIP SYSTEM WORKS

The basic concept of the CRIP system is to keep the burn zone growing in the upstream direction--with respect to the gas flow in the horizontal injection pipe--by cutting off or perforating the injection pipe at successive new upstream locations, which successively become the new injection points. A simplified design of the CRIP system is illustrated in Fig. 1. A horizontal borehole is drilled along the bottom of the coal seam either from an underground gallery or access well or by directional drilling from the surface. Standard well casing is cemented into the curved or waste part of the hole to protect against leakage to the surface, and the injection piping is inserted through this casing into the uncased horizontal portion, which extends as far as drilling ease permits along the bottom of the coal seam.

Forward combustion is started at the far end of the injection pipe (near the production well) and is continued at a convenient rate until the burn cavity has grown so large that the product gas

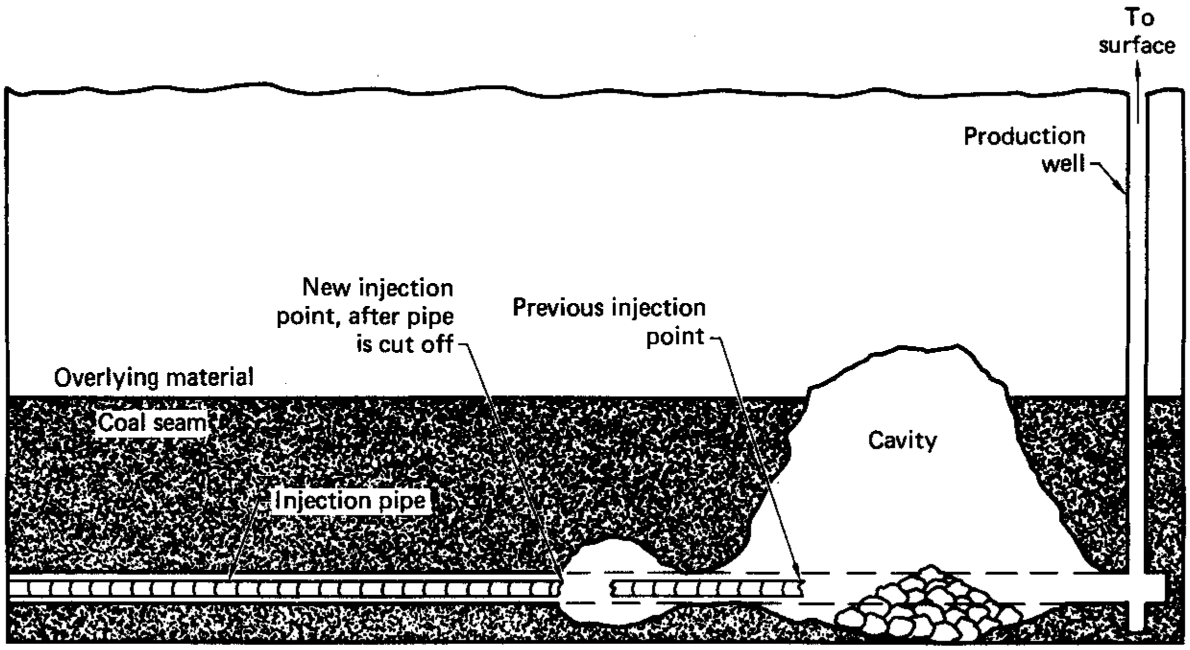

FIG. 1. Basic design of the controlled retracting injection point (CRIP) system. As the cavity burns toward the left, the injection point is moved to the left also, step by step, by cutting off or perforating the injection pipe, which can be done remotely from the surface. Thus the injectant gas is always being fed to a zone of the coal seam where unburned coal remains to be gasified.

quality has deteriorated to an unacceptable level, which happens after the burn has reached the seam roof and appreciable roof collapse has occurred.

At this time, a wire-line tool (illustrated in Fig. 2) is inserted through a gas lock on the injection pipe and pneumatically forced down the pipe to a predetermined position some meters from the end of the pipe. This tool carries an explosive charge which is detonated from the surface to cut the injection pipe and allow the injected gas (oxygen-steam mixture or air) to contact the fresh coal at that point. The injection flow is adjusted to allow reverse combustion to bring the burn zone back to the new injection point, and then forward combustion is reestablished at the normal rate.

Thus a new combustion zone is formed with good contact of oxidant and coal and low heat loss to inert material. Gas quality will again be high until the new cavity approaches the dimensions of the old one, at which time the wire-line pipe cutter is used again and the injection point is moved back another increment. This procedure is repeated over and over until the entire length of horizontal hole is used up.

VARIATIONS OF THE SYSTEM

The wire-line casing cutter is only one of several possible remote cutting methods. Other possibilities are use of a small-diameter retractable tube inside the injection pipe to inject a pyrophoric substance such as triethyl borane (or a solid, thermally active substance such as thermite) into the oxygen stream, to melt the injection pipe at the desired location. Any scheme may be applicable, as long as it permits breaking or perforating the injection pipe at a predetermined location, so as to cause the burn zone to retreat to that location.

There are several possible geometries for the gas production well. One can use a vertical well that intersects the end of the horizontal hole, as in Fig. 1; or one can use another horizontal hole in the seam, parallel to the injection hole and linked to it by one of the standard linking techniques, as in Fig. 3. A

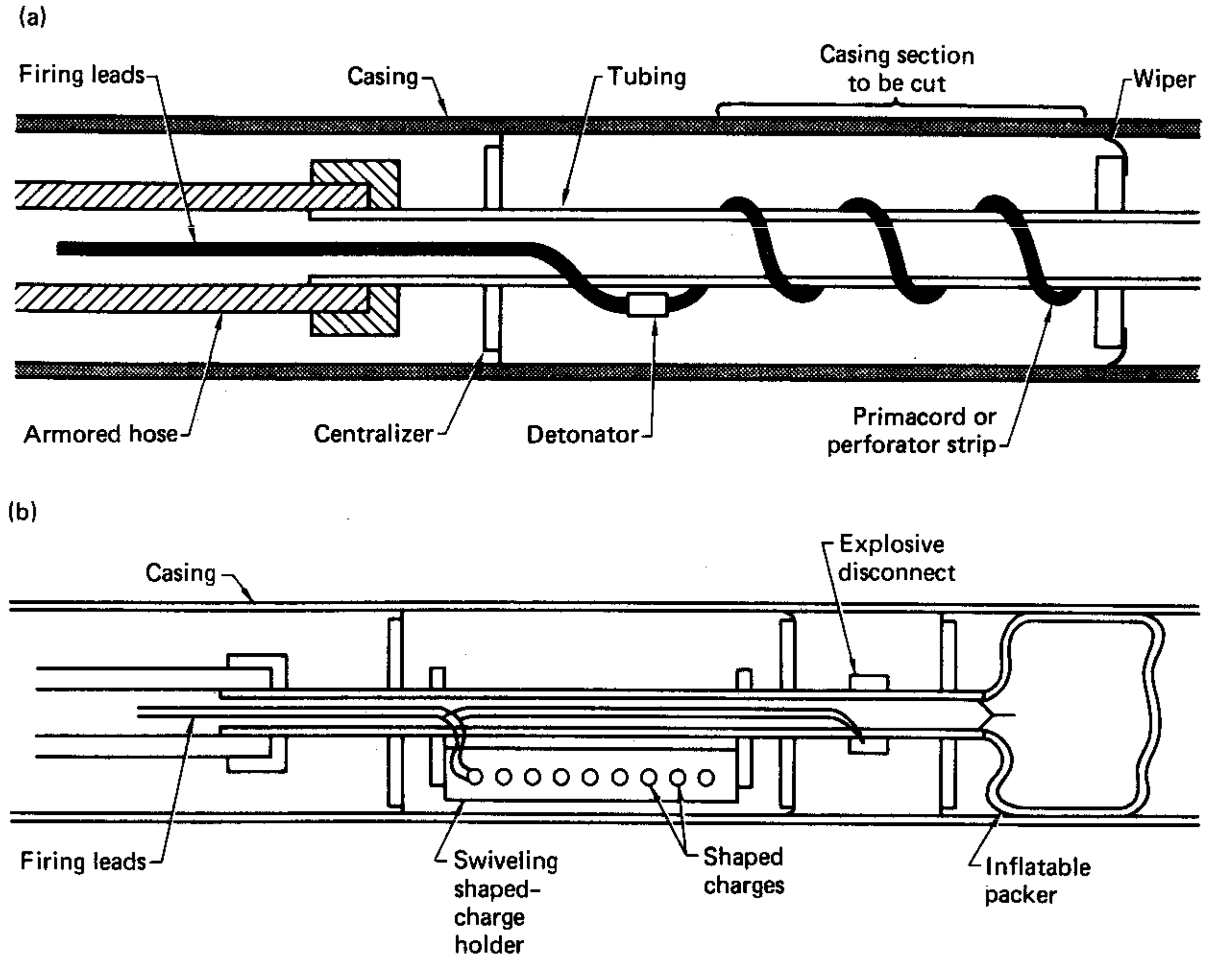

FIG. 2. Two ways in which injection pipe (casing) can be cut to yield a new injection point. (a) Explosive charge shears off end of pipe. (b) Shaped charges perforate pipe.

third possibility, with particular applicability to thick seams, is a horizontal hole at the top of the coal seam, vertically above the horizontal injection hole and linked to it by vertical drilling, as in Fig. 4.

Some of the early work in the Soviet Union with the stream method in dipping coal seams used a consumable injection pipe.[2] Thin steel pipe sections were inserted at intervals to be consumed by the burn, and the point of air injection would move up-dip as the burn zone moved up. This method was impossible to control and was abandoned after a few trials. The Soviets also tried using an uncased injection well, but that too was stopped because of control problems.

Although there is a critical injection velocity above which reverse combustion will not occur, it is very difficult to use this relationship as a means of maintaining the injection point at a given spot. As the coal dries due to the injection flow, the critical velocity changes, and reverse combustion may move the injection point against the flow even if the flow is maintained constant. The result could be a change in position of the burn front contrary to the desire of the operator, leading to a breakdown of the gasification system.

Using water injection to control the reverse burn[3] is an interesting possibility, but it means giving up the freedom to change the steam/oxygen ratio to improve gas quality, if changing that ratio would impair control of the burn.

There is some evidence in the Russian literature[4] that directing the injection

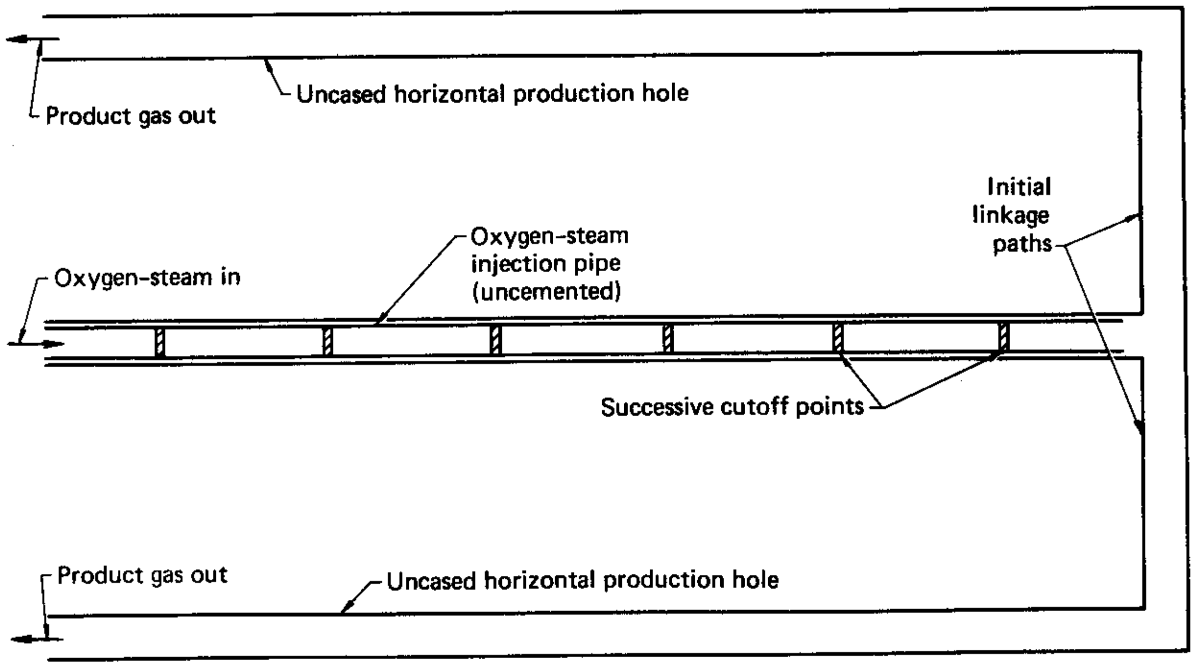

FIG. 3. Plan view of stream method adaptation of the CRIP system, with both injection and production holes drilled at the bottom of the coal seam. This version would be advantageous for dipping seams where slag accumulation in the bottom of the cavity might plug a down-dip production well.

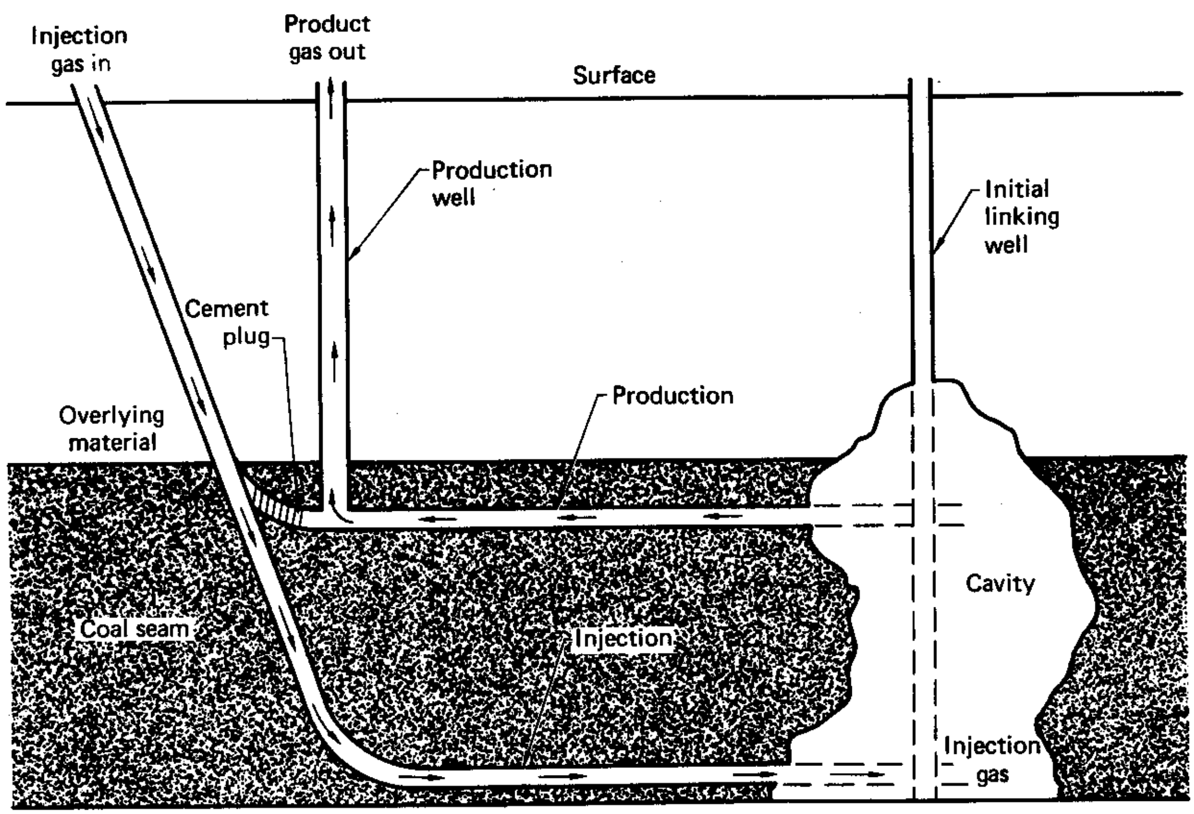

FIG. 4. Vertical cross-sectional view of a module of a commercial CRIP system, in which the injection hole is at the bottom of the seam, while the production hole is at the top of the seam.

flow with a nozzle in the horizontal plane can improve both resource recovery and gas quality. If future experiments verify this effect, the explosive casing cutter can be modified rather simply to act as an adjustable packer, and with a gravity-oriented holder for shaped-charge perforators, vent holes can be cut in the side of the casing as needed, as shown in Fig. 2(b).

The CRIP method will produce the highest gas quality possible, commensurate with acceptable resource recovery. If the cavity is allowed to grow until the roof is barely reached before the injection point is retracted, then the gasification takes place entirely within the coal seam, with minimum heat loss. A wider burn can be achieved by allowing more roof interaction so that heat loss is increased, at the cost of a reduction in gas quality. Thus the operator has a control method which will allow optimum gasification of any type of coal seam.

Plugging of flow by slag is a potential problem with all in situ gasifying methods, including our CRIP method. However, the wire-line explosive casing cutter can be used to recover from such a situation by moving the injection point away from the plug and fracturing a path through the slag, and perhaps also fracturing coal to create additional coal rubble in the burn cavity.

As mentioned earlier, the CRIP system can be applied with a number of different production geometries. For the linear design shown in Fig. 1, the burn is started fairly near the production well, but far enough away so that the cavity can grow without destroying the well. The injection point is moved back away from the production well as required to maintain the desired gas quality. This procedure will leave a long, rubble-filled cavity for the product gas to flow through on its way to the production well. As long as the collapsed roof material is porous enough to allow free passage of the gas, this geometry will work satisfactorily. Several parallel systems can be operated simultaneously to produce the desired gas volume. These systems can be spaced so that the cavities will join and thus consume all of the coal, or so that the cavities remain separated by coal barriers to minimize subsidence. In either case, the CRIP method of operation will provide maximum control of the burn geometry.

For situations in which the collapse zone fill has low porosity and impedes the gas flow, the stream method design shown in Fig. 3 would be more appropriate. This arrangement will be especially advantageous for dipping seams where slag accumulation in the bottom of the cavity might plug a down-dip production well.

Using the CRIP system for dipping coal seams should allow a reduction in the number of wells necessary for gasification. The flow impedance will remain relatively constant as the burn moves up-dip, and thus there should be no need to add additional injection wells to compensate for excessive pressure drop in the collapsed zone.

For thick coal seams the vertical stream design shown in Fig. 4 has some interesting features. The uncased production channel is at the top of the coal seam and thus is immune from collapse damage. The coal is consumed from beneath the production channel, so collapsing coal falls back on the injection point, forming a coal rubble bed to improve the dispersion and contact of the injectant. Roof collapse, which can be catastrophic for vertical wells in thick seams, cannot interfere with the process in this geometry since both injection and production wells can retreat into solid coal.

HOW THE CRIP SYSTEM IMPROVES PRODUCT GAS QUALITY

A simple gas-compositional model developed by Thorsness[5] can be used to illustrate the improvement in gas quality possible by using the CRIP system. Two cases are presented in Table 1: the observed results from the Hoe Creek No. 3 experiment, and the results under ideal conditions, assuming no water influx and no heat loss. Obviously these ideal-case results would not be achieved in practice, but one could approach the ideal as closely as desired by restricting the interaction of the burn with the roof. The trade-off between gas quality and maximum coal consumption per hole pair would be decided by the economic considerations of each situation.

TABLE 1. Comparison of observed results for the Hoe Creek No. 3 experiment and calculated results obtained with the model.

	Hoe Creek No. 3 observed results	Calculated results assuming no water influx and no heat loss
Mole fractions (dry):		
H_2	0.38	0.44
CO	0.11	0.34
CO_2	0.45	0.18
CH_4	0.05	0.05
C_2H_6	0.003	0.003
Tar/dry	0.001	0.001
H_2O/dry	1.2	0.51
Quantities relative to amount of O_2 injected:		
Water influx (mol water/mol O_2)	2.4	0
Steam injection (mol steam/mol O_2)	1.1	2.2
Heat loss (kJ/mol O_2)	142	0
Heat of combustion of product gas (kJ/mol O_2)	570	1756
Coal consumed[a] (mol coal/mol O_2)	1.85	3.77

[a]Hoe Creek coal has the following characteristics:

Weight fraction H_2O	0.3011
Weight fraction ash	0.041
Pseudo molecule	$C_1H_{0.89}\,O_{0.19}$
Density of native coal	1350 kg/m^3

COST ESTIMATES

The system design illustrated in Fig. 4 can be considered as a module of a commercial system, as shown in Fig. 5. It is interesting to calculate the underground construction costs for such a system, using the drilling costs assumed by Stephens in his analysis of linking costs.[6] If we assume that the 2-to-1 cavity aspect ratio determined in the very small laboratory tests remains valid for thick-seam gasification, then for a 100-ft-thick seam we would have a 50-ft burn width when the burn reaches the roof. At a 20-mol/s oxygen injection rate we would burn a cavity about 300 ft long in one year.

Let us assume a horizontal drilling capability of 900 ft so that each injection-production hole pair will last three years. For a seam depth of 1000 ft, we require about 1600 ft of curved hole from which both injection and production holes are drilled. Thus, for

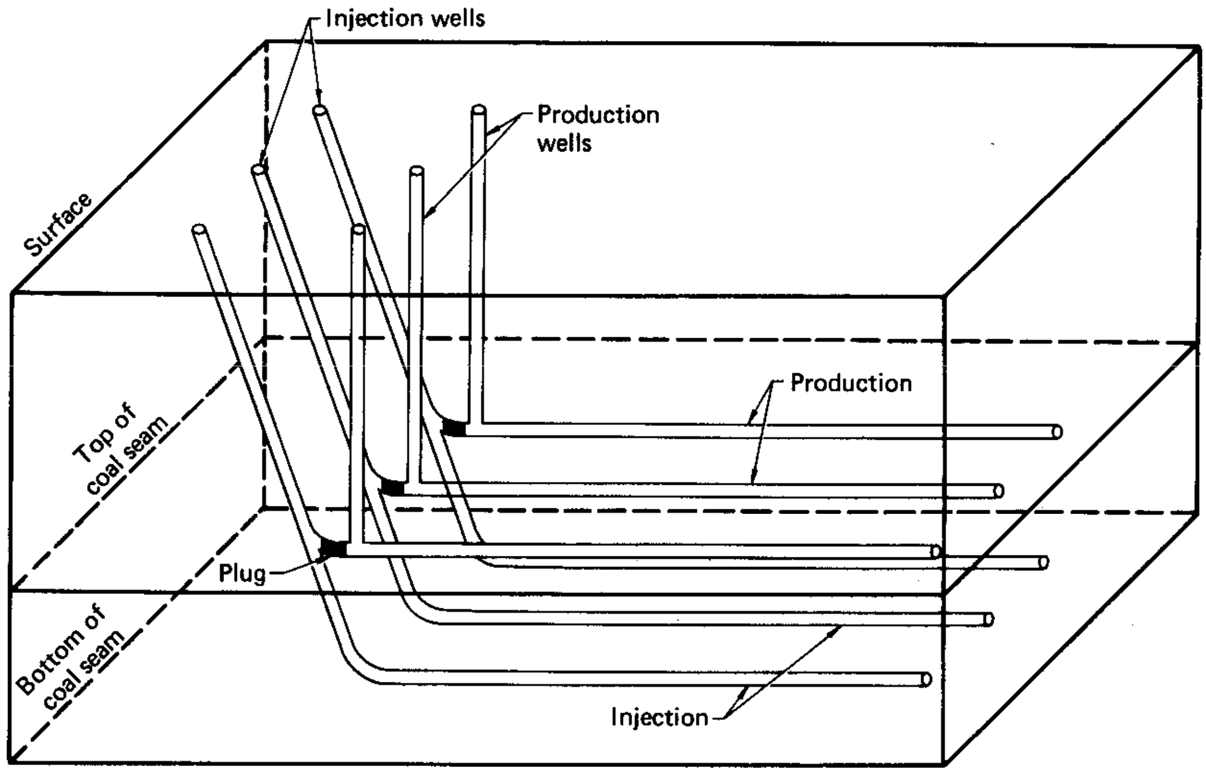

FIG. 5. Artist's conception of how several of the modules of Fig. 4 would be joined together in a commercial gasification operation.

each module, we have 3600 ft of hole at a cost of $120/ft, for a total of $432,000 per module. At $36/ft for vertical drilling costs, the production well adds $36,000 for a total drilling cost of $468,000 per module, assuming that directional control of the production channel is used to connect with the injection well. Thus, with a burn velocity of 300 ft/yr, the yearly cost is $156,000.

Using the no-heat-loss composition and the 50-ft burn width assumption, we calculate that the yearly energy production is 10^{12} Btu per module. Thus the linking cost per 10^6 Btu is $0.16, which compares favorably with the estimates in the Stephens paper. If the burn width is greater than 50 ft, which seems quite reasonable, the costs decrease so that for a 100-ft burn width (equal to the seam thickness), the cost is only $0.08 per 10^6 Btu.

CONCLUSIONS

The controlled retracting injection point or CRIP system is designed to keep the injection point on the bottom of the coal seam and to move it backwards away from the collapse zone into fresh, solid coal. The principle of controlled retraction allows the operator to choose the optimum time and distance to move the injection point, and consequently the burn zone, to get the best possible performance from the gasifier.

Although this system will work with coal seams of any thickness, it is particularly well suited to thick coal seams where the cavity grows by coal collapse as well as combustion. Placement of the production channel at the top of the seam above the injection well ensures isolation from the effects of collapse and reduces the risk of plugging the production well.

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